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A PRESEASON HURRICANE OF SUBTROPICAL ORIGIN

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ABSTRACT

The occurrence of the May 1951 hurricane of subtropical origin in the western Atlantic before the beginning of the usual tropical storm season was precedent-setting. Through an analysis of the hurricane an attempt is made to explain (1) the unusually early occurrence, (2) the difference between this hurricane of subtropical origin and the usual tropical storm, and (3) the movement as related to vertical structure, upper air flow, and distribution of ocean surface temperatures. The analysis suggests that the following factors contributed to the intensification of the incipient storm which began in connection with a cold high-level Low: (1) superposition of a divergent upper-wind field; (2) heating of the surface layers of the air mass by the Gulf Stream; (3) occurrence of unusually low temperatures at high levels. The movement of the surface center is found to be in accord with the stream flow at the top of the warm core between the 700- and 500-mb. levels. A possible influence of the ocean surface temperature distribution is suggested on the basis of a striking coincidence between the Gulf Stream axis and the storm track.

CONTENTS

	Page
Abstract.....	189
Introduction.....	189
Conditions preceding formation of hurricane.....	190
Some features of cyclogenesis.....	191
Ocean surface temperature pattern.....	192
Effect on cyclogenesis.....	192
Possible effect on movement and decay.....	193
Vertical structure related to movement.....	194
Conclusions.....	195
Acknowledgments.....	195
References.....	195

INTRODUCTION

The hurricane season in the western Atlantic area is generally acknowledged to be June through November. However, on the morning of May 17, 1951, a ship about 125 miles east of Daytona Beach, Fla., reported winds of 50 to 60 m. p. h. and waves 25 to 30 feet high. This was the first positive indication that a weak subtropical vortex had begun the intensification that was to result in a precedent-setting early season hurricane. Later in the day, aircraft reconnaissance confirmed the existence of a storm center about 80 miles off the Florida coast moving

slowly southward, accompanied by winds of hurricane force. Subsequently the hurricane produced wind speeds of over 100 m. p. h. It aimed first at the Florida coast, but looped across the extreme northern Bahamas, then feinted at the middle Atlantic coast before turning eastward off the Virginia Capes. The track is shown in figure 1.

Although this hurricane was unique in that it was the first of its type noted so near to the United States coast outside the usual tropical storm season, a study of weather maps of the Atlantic area reveals quite similar cases of hurricanes, or near hurricanes, in the subtropic Atlantic even in midwinter. These have been far at sea for the most part, in the lesser-traveled portions of the Atlantic, and have therefore attracted little notice. Simpson [1] and Riehl [2] have called attention to this fact, and the Atlantic maps reveal an example as recently as January 1951 in which a storm, devoid of fronts and exhibiting most of the characteristics of a tropical storm, produced a wind speed of over 60 m. p. h. north of the Leeward Islands.

Analysts familiar with the North Atlantic recognize the cold-core Lows which occasionally appear at high levels

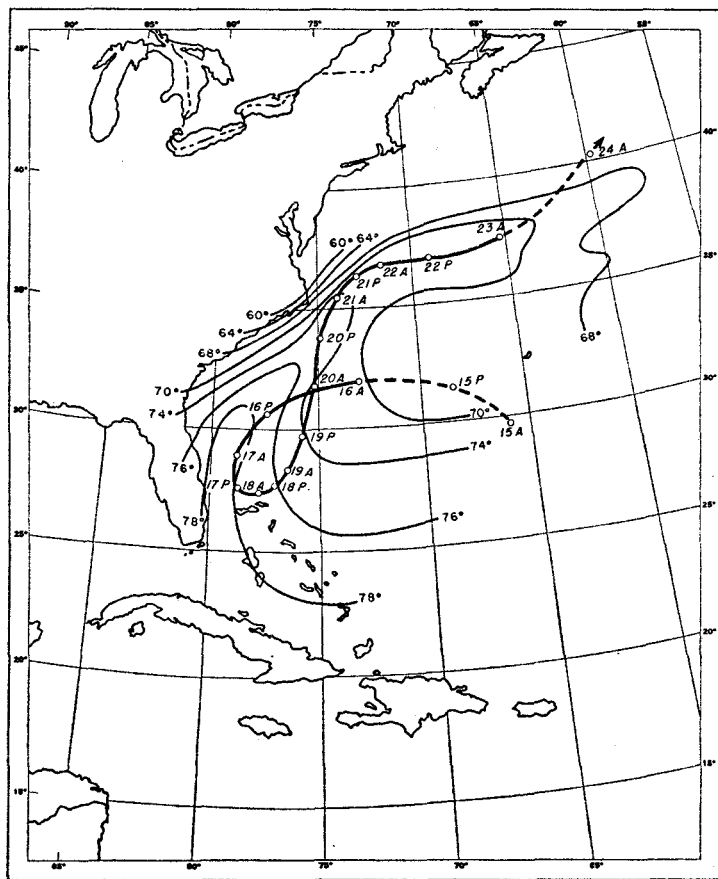


FIGURE 1.—Average May ocean surface isotherms ($^{\circ}$ F.) (thin lines) and hurricane track May 15-24, 1951 (heavy line; broken portions of track represent incipient and dissipating stages; open circles give positions of storm center on dates indicated by plotted numbers with A for a. m. and P for p. m.).

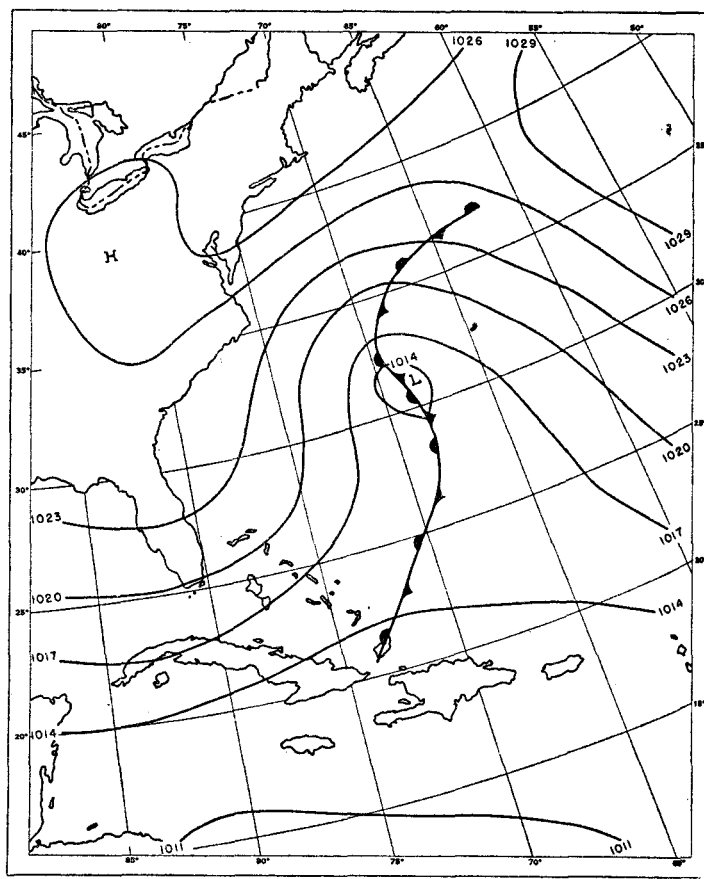


FIGURE 2.—Sea level weather chart, 1930 EST, May 15, 1951.

southwest of the Azores, frequently extending their influence downward to induce a surface low pressure center. The upper-level systems often drift southwestward but the surface perturbation may follow a curved path, apparently under the influence of the upper-level winds. Some of these move southwestward and behave much as tropical storms; others move northward, encounter a colder air mass, and develop as wave disturbances. Simpson [1] has described similar systems in the Pacific near the Hawaiian Islands, known as "Kona" Lows, some of which develop into severe storms with tropical characteristics. He found these to be very delicately balanced thermodynamically, ordinarily cold-core but becoming warm-core in the lower levels coincidental with the development of the wind and rainfall profiles of tropical storms. Many such cases of cyclogenesis in the subtropical Atlantic outside the usual hurricane season do not lend themselves to frontal analysis, nor do they have the exact characteristics expected of a tropical storm. The May hurricane falls in this category.

The purpose of this paper is to analyze the precedent-setting hurricane of May 1951 in an attempt to explain three features of the storm: first, the reason for the occurrence preceding the beginning of the usual tropical storm season; second, the difference between this hurri-

cane, originating in the subtropics, and the usual tropical storm; third, the movement as related to the vertical structure of the hurricane, and the possible effect of the ocean surface temperature distribution.

CONDITIONS PRECEDING FORMATION OF HURRICANE

On May 12, an active cold front in a sharp low pressure trough passed eastward from the Atlantic coast. By the 13th it was near Bermuda. At first the trough was marked at the surface but not pronounced aloft. However, active cold air advection to the rear of the trough was apparent and the wave at the 500- and 300-mb. levels increased rapidly in amplitude. By the 14th a closed Low had formed and was completely secluded from the westerlies. Continued cold air advection had resulted in 300-mb. temperatures as low as -45° C. just east of Florida, in the western portion of the high-level Low. This is about 7° lower than the usual seasonal values. Concurrently, modification of the air mass in the lower levels west of the front was proceeding rapidly. At the 850-mb. level the warming amounted to about 5° C. on the 13th and 14th. The area in which this modification was taking place corresponds with the axis of the Gulf Stream where water surface temperatures are about 25° C. in May. Warming of the air to near the water temper-

ature in the lowest level and to 10°C . at 850 mb., while -45°C . prevailed at 300 mb., was obviously conducive to instability.

With the warming in the lower levels, the polar trough had weakened. In fact, at the 700-mb. level a col separated it from an induced wave in the easterly current farther south. This pattern continued with little change through May 15. The first conclusive evidence of the circulation of the incipient storm was at 1930 EST on May 15 (fig. 2). In the absence of sufficient reports to guarantee an exact analysis, the map was drawn to show the eddy originating at the stationary front. It may have begun as a minute vortex farther to the east, possibly initiated by a minor easterly wave. It is of no great moment since the front was rapidly dissipating and little more than a slight wind velocity shear-line remained. As the polar air mass was becoming greatly modified, and the air was practically homogeneous, it was impossible to delineate the front on subsequent charts.

For the 24 hours following its appearance at 1930 EST on the 15th, the weak surface vortex moved in an arc closely parallel to the 700- and 500-mb. level contours. There was little deepening of the surface system during this period. At the same time the upper-level Low, beneath which the surface eddy was drifting, showed a slight movement towards the southwest. By 1930 EST of the 16th, the surface perturbation had moved to a position over the warmest portion of the Gulf Stream (fig. 1).

SOME FEATURES OF CYCLOGENESIS

Simultaneously with the arrival over the Gulf Stream, the vortex was reaching a position where the circulation in the upper troposphere appeared favorable to deepening. It is generally agreed that high-level divergence is a necessary element in the mechanism for the mass removal of air from the central portions of a hurricane. Previously, a field of convergence at high levels was over the path the surface center had followed. Now as the center was passing under the influence of the wind field between the upper cyclone and the High to the northwest, upper divergence was more in order. (See fig. 3.) Riehl [3] has described the dynamics of such superposition of high- and low-level pressure systems brought about by the interaction of the polar westerlies and the trades. This superposition appears to be one of the important factors in tropical cyclogenesis. Roland and Plouff [4] have also noted the applicability of this hypothesis to the May hurricane.

A clue to a source of energy for cyclogenesis can be found in the vertical structure of the air. Figure 4 is a sounding taken at Miami, May 16, 1951, at 1500 GMT. While it cannot be stated positively that this is representative of the vertical structure of the air in which the storm formed, there is good evidence that it is. At Tampa, also

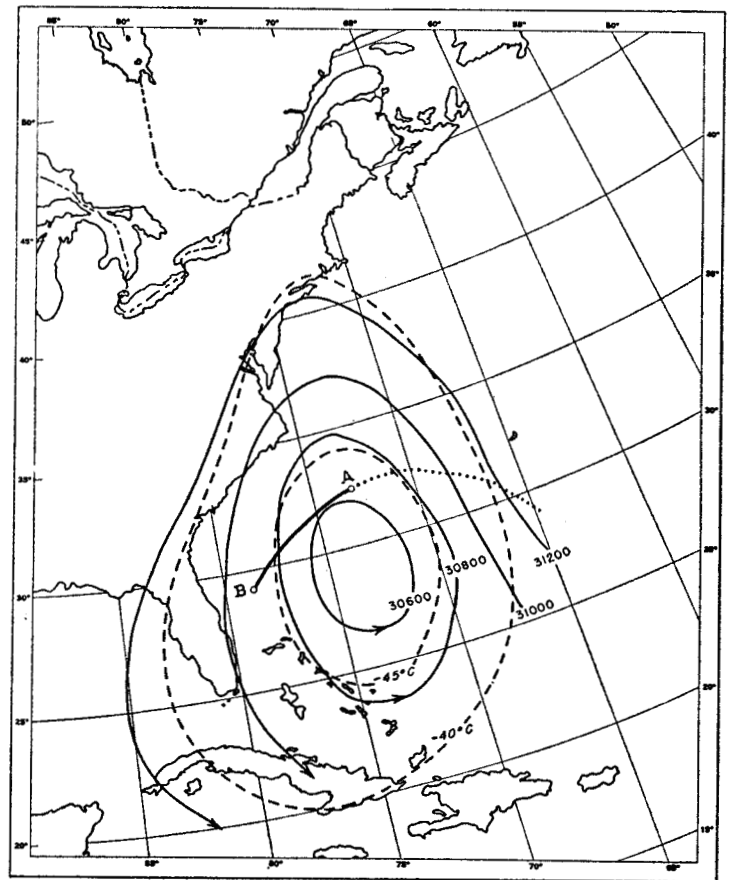


FIGURE 3.—300-mb. chart, 1000 EST, May 16, 1951. Contours in feet (thin solid lines); isotherms in $^{\circ}\text{C}$. (dashed lines); sea-level path of incipient vortex (dotted line). A is the position of first definite closed circulation. From A, the vortex followed track (heavy solid line) to B, the position of deepening to hurricane intensity.

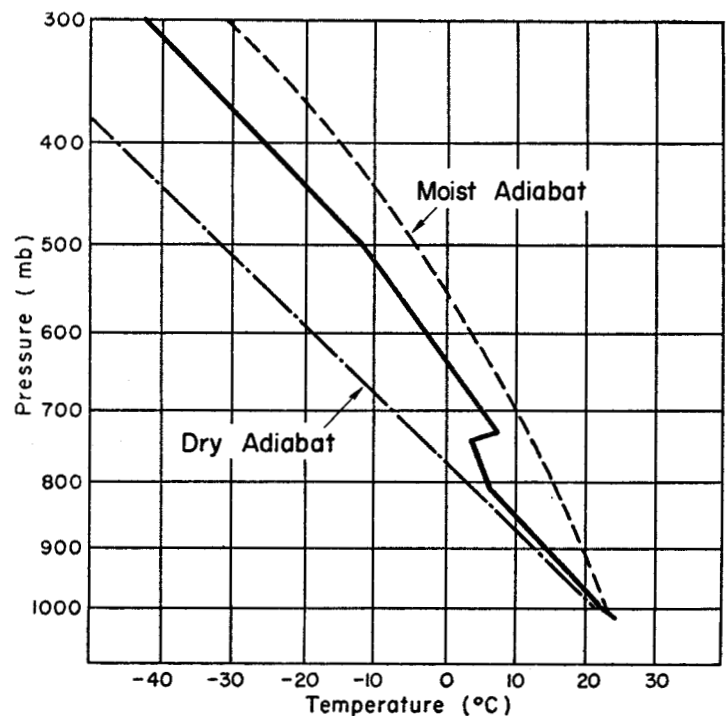


FIGURE 4.—Upper air sounding at Miami, Fla., 1000 GMT, May 16, 1951.

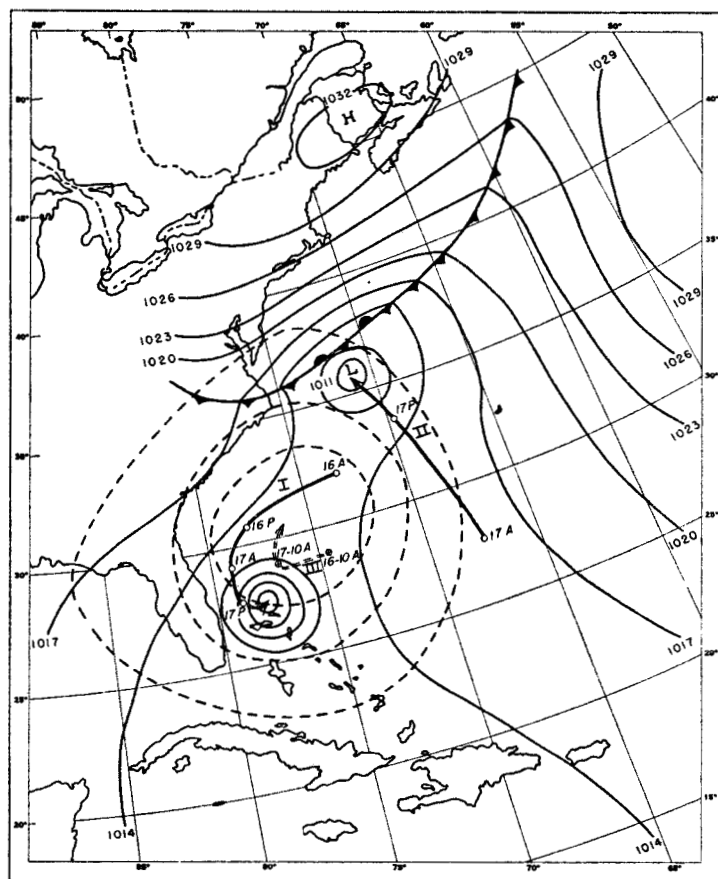


FIGURE 5.—Sea level weather chart, 0730 EST, May 18, 1951, with superimposed 500-mb. contours (dashed lines) 2200 EST, May 17, 1951. Arrows indicate: I—path of hurricane; II—path of secondary Low; III—path of 500-mb. Low.

in the same general air stream downwind from the point where cyclogenesis occurred, a similar sounding curve was obtained. Furthermore, both soundings showed the characteristic subsidence inversion of the southern edge of the High and the rather steep lapse rate below the inversion, produced by the rapid surface heating.

Up to a certain point, the inversion was sufficient to restrict convection, concentrating the moisture below the 700-mb. level. However, as the surface vortex moved across the axis of the Gulf Stream, three influences united to extend the convective processes to higher levels. These were: (1) active surface heating; (2) convergence in the surface layers; and (3) highly unstable lapse rate above the inversion. Strong convective instability existed between the surface and the 300-mb. level, or higher, and this apparently supplied a large amount of energy for the cyclogenesis.

Before some further aspects of the vertical temperature distribution and its implications are discussed it may be well to emphasize the importance, in the deepening of the surface vortex, of the concurrent features already mentioned. It might be noted that a second vortex (see fig. 5) with quite similar characteristics, lacked two of these potent factors in its history and failed to produce winds of more than about 45 m. p. h. The factors missing

in this case were (1) trajectory over the warmest portion of the Gulf Stream, and (2) divergence at upper levels, which was not present in the eastern section of the high-level Low. This is attractive circumstantial evidence of the importance of these two factors in the development of the first vortex, and the failure of the second one similarly to intensify. However, sufficient data are not available to draw any positive conclusions.

With respect to the lapse rate and moisture distribution prevailing in the area in which the storm developed, the following appears pertinent: Riehl [3] has suggested that the optimum conditions for tropical cyclogenesis require that the temperature distribution and moisture content of the air be such that large scale vertical circulations can develop. He points out that if the air mass which is subjected to surface convergence and forced ascent is not saturated, sufficient cooling will take place in the rising air, contrasted with adiabatic warming in the descending current, to nullify the horizontal temperature gradient of the convective cell. The central portion of the storm would then become cooler than its surroundings and the circulation would die. In a nonsaturated air mass, only local and small-scale vertical overturning would occur, resulting in the dissipation of the energy in local showers. In the present case, an inversion (fig. 4) was present to cap the convection and the intense flux of heat and moisture from the warm surface was confined to levels below the 700-mb. surface.

The modified polar air was still not as moist as maritime tropical air. (This fact was subsequently borne out by the lack of rainfall as heavy as that of the usual tropical storm.) However, the air was becoming very unstable and the moisture content was increasing. Furthermore, the moisture deficiency was to some extent compensated for by some other unique features of this storm.

OCEAN SURFACE TEMPERATURE PATTERN

EFFECT ON CYCLOGENESIS

One of the unique features of the storm was its path over the warmer portions of the Gulf Stream at a time of year when the temperature difference between it and the surrounding waters is quite marked (fig. 1). This path resulted in a continuous supply of warm air from the surface being available to the central portion of the storm. Less rapid modification of the surrounding air mass assisted in maintaining the proper temperature gradient between the inner and outer portions of the circulation.

In a recent study, Mantis [5] states: "If the cyclone is considered a thermodynamic engine for transforming heat energy into kinetic energy . . . only the radial difference in heating aids the process and the total amount of heat added is not important." In view of this, the storm's position over the Gulf Stream at the time of intensification would assume special importance. In addition to the contribution of the Gulf Stream heating to the vertical

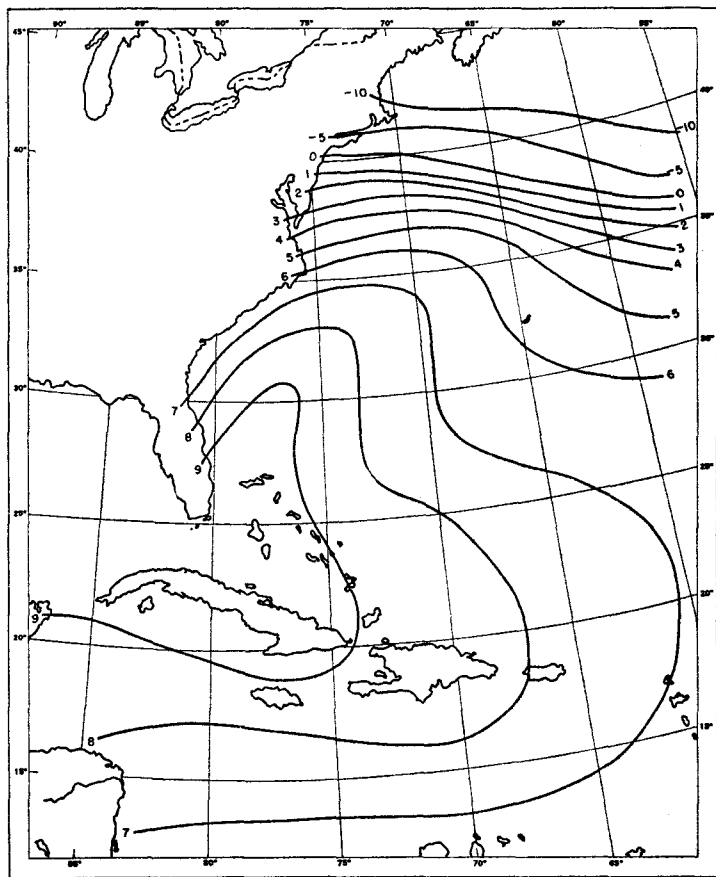


FIGURE 6.—September instability index lines showing difference ($^{\circ}$ C.) between temperature of air lifted adiabatically from sea surface to 300 mb. and average free air temperature at 300 mb.

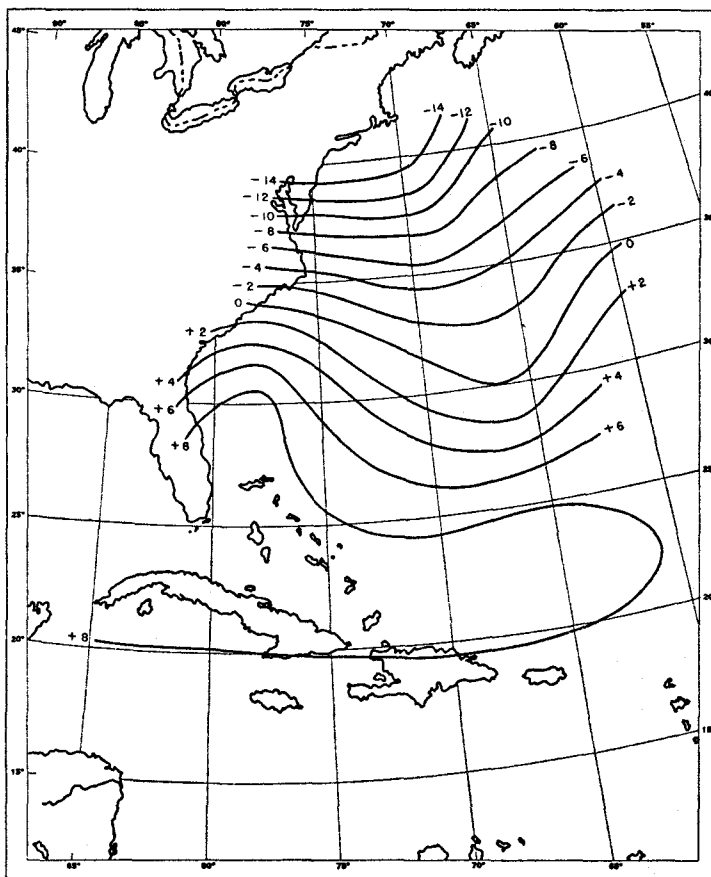


FIGURE 7.—May instability index lines showing difference ($^{\circ}$ C.) between temperature of air lifted adiabatically from sea surface to 300 mb. and average free air temperature at 300 mb.

instability, the radial temperature gradient was also affected by the unusual distribution of the heat source, i. e., the center of the vortex was over the warmest portion of the Gulf Stream while the outer portions of the cell were over somewhat cooler waters. The importance of this unique feature may be a partial explanation of why this was one of the more intense storms to develop in the subtropics.

If air overlying an ocean is assumed to have been modified until the temperature of the lowest layer approximates that of the water surface and has an average humidity of 85 percent—not an unlikely condition—and then is lifted adiabatically to 300 mb., the difference in the resultant temperature and the average air temperature at 300 mb. is a rough index of the instability energy available. On this basis, Palmén [6] constructed charts of this value for the Atlantic and Caribbean and examined the likelihood of hurricanes in the various oceanic areas from the standpoint of vertical instability considerations. Figure 6 is a chart of this index for September, about the peak month of hurricane activity in the western Atlantic. Figure 7 gives the same data for the month of May.

Although the water temperatures for any given month are not likely to vary much from the average values used, there is considerable aperiodic variation in the temperature

at the 300-mb. level. Comparison of figures 6 and 7 shows that the instability index actually averages less for May than for September, apparently due to the spring lag in warming of the ocean surface. This is in contrast to the spring maximum of instability over land. If, however, the absolute minimum temperatures at 300 mb. are used instead of the average values, it is found that the instability in May (index 18) exceeds the maximum likely in September (index 16). In the case of the May 1951 storm, it was extremely cold at high levels and the instability criterion approached the maximum May value, so that the instability was somewhat greater than is likely in any peak-of-season hurricane. This large degree of vertical instability resulting from cold high-level Lows over warm water surface appears to be an important, possibly a primary, factor in the development of many of the storms that occur in the subtropic belt, especially outside the usual hurricane season.

POSSIBLE EFFECT ON MOVEMENT AND DECAY

The great amount of instability energy available in the development stage of the hurricane was noted. If the vertical temperature distribution on May 21 is investigated along the lines discussed in the preceding section, it is found that, as illustrated in figure 8, a temperature of

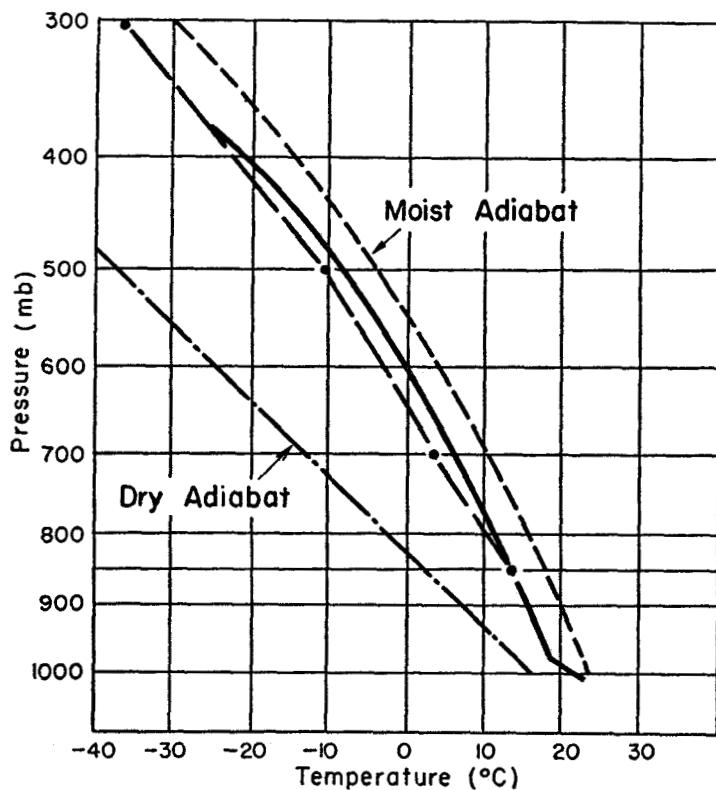


FIGURE 8.—Vertical temperature distribution (dashed line connecting dots) at 36° N., 74° W. as interpolated from constant pressure charts, 1000 GMT, May 21, 1951. Temperature of parcel lifted adiabatically from original temperature of 70° F. and 80 percent saturation at sea level is shown by solid line. Note that lower surface temperature would not favor convection.

approximately 70° F. in the surface layer would be required to maintain the convective cell. Figure 1 shows how definitely the vortex curved abruptly eastward along the Gulf Stream axis, keeping within the area enclosed by the 70° ocean surface isotherm, and upon reaching the outer limit of this area, rapidly dissipated. No claim is made here that the control of the heating in the lower layers by the distribution of the water temperature was the determining factor in either the development or the path of this hurricane. However, the evidence certainly points to the conclusion that the ocean surface temperature charts should be given close attention in any forecast for storms developing in the subtropics since the vertical temperature distribution is especially critical in this type of cyclone. Furthermore, during the cooler seasons in which these storms occur, the water temperature contrasts are greater and currents such as the Gulf Stream more clearly defined.

VERTICAL STRUCTURE RELATED TO MOVEMENT

The concept of a steering level for tropical storms has been advanced and used with considerable success by Grady Norton of the Miami Hurricane Center (c. f., Gentry [7]). Basically, the theory is that the surface center will move approximately parallel to the wind

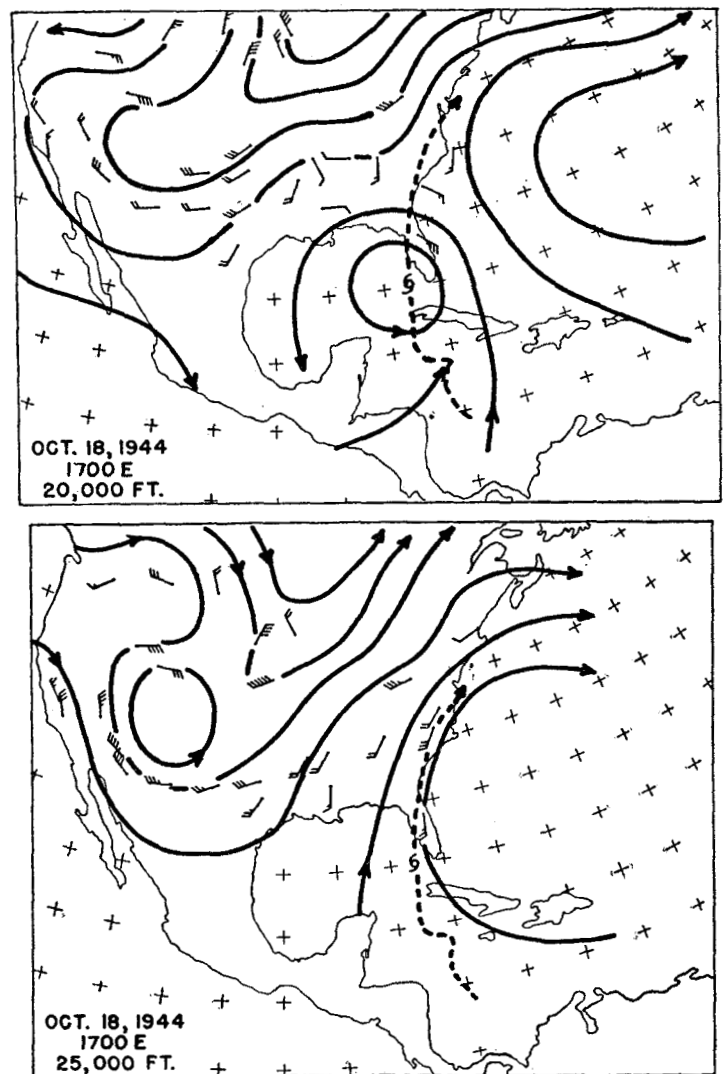


FIGURE 9.—Example of application of steering level concept to hurricane of October 18, 1944. Charts show streamline analysis at the 20,000-ft. level where the circulation of the storm is still closed, and at the 25,000-ft. level which is above the closed circulation. The hurricane track is shown by dashed line.

stream near the top of the warm core, which usually coincides with the top of the closed cyclonic circulation of the storm. Figure 9 shows an example of the method applied to the hurricane of October 18, 1944. Note that the closed circulation of the storm is still in evidence at 20,000 ft. but not at 25,000 ft. The storm track on the 25,000-ft. chart shows the agreement with the streamlines at that level. Figure 5 gives some indication of the correlation of a portion of the path of the May hurricane with the flow at the 500-mb. level, which apparently was the best steering level in this case. To show the complete relationship between the track and the upper flow patterns throughout the storm's history would require a lengthy series of charts, since the upper circulation was gradually changing during the 7- or 8-day period. For a more complete examination of this feature, the reader may refer to back chart files.

It does not appear that the storm circulation had disappeared at the 500-mb. level. However, analysis of the upper air charts indicates that between the 700- and 500-mb. levels there was a layer of minimum radial pressure gradient, coinciding with the top of the warm-core cell of the storm. Above this level the cyclonic circulation intensified and gradually merged with an extensive cold Low at higher levels. Fair results would have been obtained by the use of a steering level higher or lower than the 500-mb. level for certain portions of the storm's track but the best over-all correlation was found with the 500-mb. chart.

CONCLUSIONS

The analysis presented in this study indicates that a combination of several favorable circumstances led to the pre-season occurrence of the hurricane in May 1951. The hurricane began in connection with a cold high-level Low at subtropic latitudes. It appears that superposition of a divergent wind field at upper levels over the incipient storm was an important feature of the intensification. Heating of the surface layers of the air mass by the Gulf Stream and the unusually low temperatures aloft were also contributing factors. There was a striking coincidence between the track and the sea surface isotherm pattern, which indicates a possible influence of the sea surface temperature field on the storm's path. The movement of the surface center was in accord with the streamflow at the top of the warm core of the hurricane and paralleled the constant-pressure contours at about the 500-mb. level.

Storms such as this one are believed to comprise a category distinct from the extratropical, and the usual tropical cyclone. They are associated with a cold-core Low which becomes warm-core in the lower levels with intensification. The top of this warm core, and consequently of the steering level, appears to be at a considerably lower level than for a pure tropical storm with a similar radial pressure gradient.

It is felt that some distinctive term should be used to designate this particular type storm. Simpson [1] has suggested "subtropical cyclone". Further research should reveal whether it is a distinct type with no counterpart in the tropics or whether it may occur also in the tropics as a variation of the usual tropical storm structure.

ACKNOWLEDGMENTS

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REFERENCES

1. Robert H. Simpson, Evolution of the Kona Storm—A Subtropical Cyclone, U. S. Weather Bureau, Honolulu, T. H., 1951 (unpublished manuscript).
2. Herbert Riehl, "Waves in the Easterlies and the Polar Front in the Tropics," *Miscellaneous Reports No. 17*, Dept. of Meteorology, University of Chicago, January, 1945.
3. Herbert Riehl, "A Model of Hurricane Formation," *Journal of Applied Physics*, vol. 21, No. 9, September, 1950, pp. 917-925.
4. Raymond M. Roland and Ira G. Plouff, The Unusual Hurricane of May 1951, Research Section, Navy Hurricane Weather Central, Miami, Fla., June, 1951 (unpublished manuscript).
5. Homer T. Mantis, "A Model of a Tropical Cyclone in the Steady State," *Meteorological Papers*, vol. 1, No. 3, New York University College of Engineering, New York, May, 1951.
6. E. Palmén, "On the Formation and Structure of Tropical Hurricanes," *Geophysica*, No. 3, Helsinki, 1948, pp. 26-38.
7. R. C. Gentry, "Forecasting the Formation and Movement of the Cedar Keys Hurricane, September 1-7, 1950," *Monthly Weather Review*, vol. 79, No. 6, June, 1951, pp. 107-115. (See especially p. 111.)